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ART. VII.—*The Glauconitic Sandstone of the Tertiary of East Gippsland, Victoria.*

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Abstract.

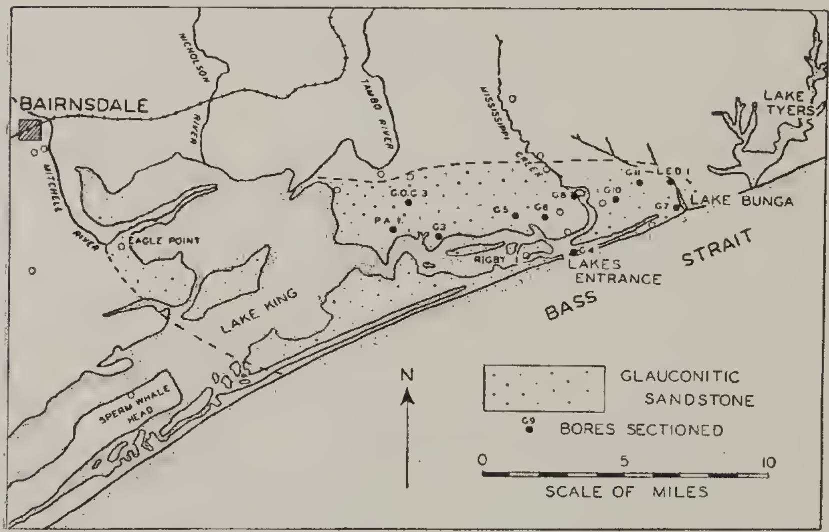
The glauconitic sandstone formation that occurs at depth in the Tertiary strata of East Gippsland, Victoria, consists of grains of altered glauconite in a felspathic sandstone, which has a cement of glauconitic mud. The glauconite grains are largely derived from the alteration of biotite flakes. They often show open shrinkage cracks that developed at an early stage of lithification. Much of the glauconite is altered to a ferruginous clay-like substance. The alteration occurred during deposition, and prior to lithification, and is not a weathering effect, although it resembles the alteration of glauconite caused by weathering.

The air-dried rock shows abnormally high porosity, and low permeability. Impregnation of the rock with coloured canada balsam reveals that the natural cement of the rock is highly porous in an air-dried state, the pore spaces being of capillary dimensions. The high porosity appears to have been induced by air-drying of the rock, and may not be a feature of the rock *in situ*.

Introduction.

The petroliferous glauconitic sandstone that occurs in the Lakes Entrance district of Gippsland has been described briefly by Crespin (1943, p. 32). In this note it is proposed to elaborate several features of petrological interest exhibited by this rock.

The glauconitic sandstone occurs at or near the base of the Tertiary strata in this part of Victoria, above a bedrock of granitic and metamorphic rocks. In places it rests directly on the bedrock, but mostly it is separated from it by a thickness of from 20 to 200 feet of Tertiary sediments. The glauconitic sandstone does not outcrop. Its limits have been defined by drilling (fig. 1). It extends from Lake Bunga in the east to Eagle's Point in the west, a distance of about 20 miles, and from the coastline northwards (inland) for a distance of from 3 to 5 miles. Its south-western limit is between Rigby Island and Sperm Whale Head. The sandstone is oil-bearing over an area of about 8 square miles in the vicinity of Lakes Entrance.



The glauconitic sandstone lies at a depth of from 960 to 1,416 feet below sea-level, the depth increasing towards the south or south-east at about 1 in 400. It has an average thickness of about 30 feet in the 40 bores that have intersected it. The maximum thickness recorded in any bore is 60 feet, in the No. 2 bore of the Lakes Entrance Development Co., near Lake Bunga in the parish of Colquhoun.

Crespin (1943) classifies the glauconitic sandstone as the lower lithological unit in the Janjukian stage of the Middle Miocene in Gippsland. It overlies Miocene strata of the Anglesean stage, and passes upwards into sandy micaceous marls which contain grains of glauconite in their lower beds.

A petrological examination of specimens from the core of the No. 10 Government bore at Lakes Entrance has been issued by Dr. F. L. Stillwell, under the title "Glauconitic Sandstone from

No. 10 bore, Lakes Entrance ", as Mineragraphic Report No. 308, of the Council for Scientific and Industrial Research. This examination was made at the request of Dr. H. G. Raggatt, Director of the Mineral Resources Survey. Porosity measurements made by Mr. R. F. Thyer, of the Mineral Resources Survey, on dried specimens from this core had given porosities as high as 35 per cent., which is much in excess of that recorded for most oil sands, while permeability measurements on the same specimens had shown them to have low permeability. The petrological examination was sought in the hope that it might provide some explanation of this anomaly, but only a partial explanation was arrived at.

This, and other peculiar features of the glauconitic sandstone revealed by this examination, indicated that a more extensive petrological study of the formation as a whole was justified. To this end material from all the available cores of other Government and private bores was examined. This material was made available by the kindness of Mr. W. Baragwanath, then Director of the Geological Survey of Victoria.

My thanks are also due to Dr. M. Glaessner, Dr. W. D. Osborne, Mr. J. Montgomery, and Professor E. S. Hills, for helpful criticism of the manuscript. The original petrological examination (Mineragraphic Report No. 308) was made in collaboration with Dr. F. L. Stillwell.

Petrology.

In the hand specimen, the glauconitic sandstone is brownish-green to brown, and uniformly fine-grained, except for occasional rounded grains of iron-stained quartz, or quartzite, a millimetre or more in diameter. Occasionally these coarser grains are sufficiently numerous to give the rock a grit-like appearance over a thickness of about half an inch. A freshly broken surface is minutely pitted owing to the breaking out of the glauconite grains from the matrix. The grains that remain in the surface look like minute pellets of limonite. Some specimens contain sparsely distributed shells, such as Turritelloids, 1 to 2 cm. long. These are generally filled with glauconitic sandstone, though a very occasional shell may be only partly filled.

Thin sections were prepared of representative samples of the sandstone from the eleven available bore cores of the bores that have encountered this formation. They are Government bores Nos. 3, 4, 5, 6, 7, 8, 10, 11, and Lakes Entrance Development Co. No. 2 bore, all in the parish of Colquhoun, Point Addis Co. No. 1 bore, and Gippsland Oil Co. No. 3 bore, in the parish of

Bumberrah. These eleven bores are so spaced as to cover most of the extent of the glauconitic standstone formation (fig. 1). From most of these cores, two samples some feet apart were sectioned, but from No. 10 Government bore, parish of Colquhoun, ten sections were cut, representing the horizons at 1,261-63 feet, 1,265-67 feet, 1,267-70 feet, 1,270-72 feet, 1,275-76 feet, 1,277-78 feet, 1,291-94 feet, and 1,294-1,300 feet. The close similarity between all the specimens sectioned leaves little doubt that they give a true picture of the composition of the sandstone formation.

Some of the bore cores had been air dried before they were received, others had been stored in sealed tins. Some had been drilled dry, and the drill cores were too hot to hold in the hand when raised; others had been drilled wet and were not heated unduly by the drilling. The differences in drilling practice and storage do not appear to have affected the state of the glauconite or the structures of the rock.

The specimens, with one exception, were too friable to section without previous impregnation. Since glauconite undergoes dehydration when heated above 70°C. (Ross, 1926; Takahishi, 1939), care was taken not to heat them unduly. The specimens were soaked in a thin, cold solution of canada balsam in xylol, and dried in an air oven at 30°C. The cemented material was then mounted and sectioned in the usual way. With some sections, it was necessary to coat the ground surface with the balsam-xylol solution and dry at 30°C. several times before a smooth surface suitable for mounting could be obtained; the same process had to be repeated during the final stages of grinding some of the thin sections. Wet specimens were dried for 24 hours at 30°C. in the air oven prior to impregnation.

The thin sections reveal that the specimens from the different bores, and from different horizons in the same bore, are closely similar in mineral composition and texture, but vary slightly in the proportion of the various constituents. They consist of numerous smooth-surfaced, oval and sub-angular grains of glauconite dispersed through a fine-grained felspathic sandstone, which consists of quartz, orthoclase, oligoclase, and abundant biotite, with minor amounts of muscovite, pyrite, iron oxides, leucoxene, tourmaline, zircon, apatite, and in places a carbonate mineral, cemented together by a greenish to greenish-yellow isotropic substance, presumably a glauconitic mud. In some sections, this glauconitic mud is largely replaced by the carbonate mineral, which is presumably dolomitic, since it is not stained by treatment with silver nitrate and potassium chromate.

Occasional tests of foraminifera (consisting of calcite) are usually present, generally with a filling of green glauconitic material.

The quartz and felspar occur chiefly as angular to sub-angular grains from 0·1 x 0·1 mm. to 0·05 x 0·05 mm. in size; in some sections the majority of the grains are water worn. In addition, there is in every section a few coarser, limonite-coated and well-rounded fragments of quartzite, quartz or felspar, a millimetre or more in diameter, dispersed through the fine-grained rock. In some sections there are also occasional well-rounded pellets of fine-grained mudstone, more or less glauconitized, of about the same dimensions (Plate IX., fig. 7). These may be of coprolitic origin. Many of the numerous biotite flakes are slightly chloritized or glauconitized. They vary in size from 0·3 x 0·1 mm. to 0·1 x 0·05 mm.

These, together with the less common minerals, are set in an amorphous or cryptocrystalline greenish to yellowish susbtance which occurs as films of cement between the individual grains where they are closely packed (Plate IX, figs. 1 and 2), and as a base through which they are studded in sections in which they are widely spaced. In some sections the width of the green cement separating the individual grains is as much as 0·05 mm. The material appears to be a glauconitic mud, and generally forms the filling of the tests of foraminifera in the rock.

The proportion of carbonate varies greatly from section to section. In some it occurs only as the tests of the occasional shells and foraminifera, but in others it is an abundant constituent of the matrix of the rock, largely replacing the green base. In several of these sections, it occurs chiefly as well-formed and slightly iron-stained rhombohedra of dolomite about 0·05 x 0·03 mm., either as isolated crystals, or in clusters. This well-crystallized dolomite is presumably of diagenetic origin.

The Glauconite.

The glauconite grains are occasionally 1·0 mm. across, but are generally between 0·5 x 0·3 mm. and 0·2 x 0·2 mm. Some of the grains are green or greenish-yellow, but the majority of grains are yellow, yellowish-brown or reddish-brown, and some closely resemble limonite in appearance, indicating that they are altered forms of normal green glauconite comparable with the alteration products of glauconite described by Gildersleeves (1932) from the weathered Eocene greensands of Virginia and Maryland, U.S.A.

Some of the altered glauconite grains are zoned, the outer zone being generally darker than the core, though some show a narrow fringe of greenish-yellow material around the brown zones. In some sections a number of the grains have a green or greenish-yellow core with a yellow or brown margin.

Many of the grains have smooth, rounded surfaces, and some have a smooth, mammillated surface. Others are angular to sub-angular. Some of the rounded grains are nearly circular, but the majority are oval. Occasional grains contain inclusions of quartz that are finer-grained than the quartz of the sandstone.

Many of the glauconite grains reveal evidence of shrinkage. Sometimes the shrinkage cracks extend more or less radially into the grains (Plate IX., fig. 3). Many of the grains have shrunk away from the enclosing matrix (Plate IX., fig. 1) or from a narrow rim of glauconite strongly cemented to the matrix. Some zoned grains show shrinkage cracks at the margin of successive zones. These shrinkage cracks appear to be similar to the fractures in weathered glauconite figured by Gildersleeves (1932). For some grains, the shrinkage cracks may constitute as much as 30–40 per cent. by volume of the grain.

The shrinkage cracks are an original structure of the glauconite, and are not due to heating during drilling, or drying out of the specimens. This is proved by the fact that, in several sections, grains of altered glauconite occur in which shrinkage cracks have developed, but have been infilled with the green or greenish-yellow material that forms the cement between the grains of the sandstone (Plate IX., Fig. 2). The pattern of the shrinkage cracks (Plate IX., fig. 2) leaves little doubt that they arise from the drying out of an originally gelatinous substance. Similar shrinkage cracks, though not so strongly developed, characterize many grains of unaltered green glauconite found at higher horizons in the Gippsland bores.

The shrinkage probably occurred during lithification. Glauconite grains which have shrunk away from the enclosing matrix (Plate IX., fig. 1) or from a narrow rim of the grain strongly cemented to the matrix, could only have done so after the rock was more or less consolidated. Where the cracks have been infilled with glauconitic mud, either the shrinkage cracks occurred at an early stage of lithification and the glauconitic mud was squeezed into the opening or carried in by connate waters, or the glauconitic mud entered cracks which had developed during deposition. In sections with abundant carbonate, the carbonate rarely, if ever, occurs in the shrinkage cracks of the glauconite grains, though in such sections the cracks are often filled with green glauconitic mud. Since the carbonate is probably diagenetic in origin, the filling of the shrinkage cracks, and hence their formation must have taken place either at an early stage of lithification or during deposition. The latter seems unlikely because the fractured parts of grains so broken by shrinkage cracks would readily have separated.

Formation of the Glauconite.

As noted by Crespin (1943, p. 33), much of the glauconite appears to have formed from the alteration of biotite in the manner described by Galliher (1935). All stages of the transition from biotite to glauconite can be seen in the thin sections. The biotite first swelled in a direction at right angles to its cleavage planes. Commonly the swelling was greater on one side of the flake than on the other, so that the swollen flake became curved (Plate IX., fig. 4). Where this unequal swelling was pronounced, the biotite flake became fan-shaped, the cleavage traces corresponding to the ribs of the fan (Plate IX., fig. 5). In this expanded state, the biotite retains its pleochroism and colour. Takahashi (1939, p. 506) indicated that the swelling is caused by hydration of the biotite, which leaves it in a gelatinous state.

At this stage glauconite developed along the cleavage planes so that the biotite became parti-coloured brown lamellae alternating with green (fig. 8); the glauconite spread laterally into the biotite until the whole of the expanded flake was converted to glauconite, in which faint traces of the biotite cleavage still remain (Plate IX., fig. 6). During this transition, the lamellae of biotite between successive cleavage planes sometimes splayed apart, and when the splayed margins became slightly rounded, they gave the glauconite a mammillated outline (Plate IX., fig. 1) that might be mistaken for the cast of a foraminifera. As the gelatinous glauconite dried, it shrank, developing rounded edges and shrinkage cracks.

The well-rounded outlines of many of the glauconite grains, and of some of the expanded biotite flakes, contrast strongly with the distinctly angular form of many other grains of glauconite and expanded biotite (Plate IX., fig. 1). The rounding may be due to attrition during deposition or, more probably, as Galliher (1935) suggests, to passage through the intestines of worms while in a gelatinous condition.

The zoned character of some of these grains in their altered state is presumably due to the inward progression of alteration rather than to any original zonal structure on the glauconite grains.

The biotite flakes in their unaltered state are about 0·3 x 0·1 mm. or smaller. On expansion, the length of 0·3 mm. remains unchanged, but the width of 0·1 mm. increases to 0·5 mm. and occasionally even to 1·0 mm. This accounts for the distinctly larger grain size of the glauconite grains as compared with most of the other mineral constituents of the sandstone. Prior to the hydration of the biotite, and apart from the occasional, well-rounded, coarse grains of quartzite and pellets of mudstone, the detrital grains were well sorted. The size distribution of the grains appears to agree with that figured by Takahashi (1939, p. 511) for typical glauconite sandstones. The presence of the occasional, well-rounded, coarse grains is probably due to the fact that they would roll more readily under the action of relatively weak currents or wave movements than angular particles of the same size.

A small proportion of the glauconite grains have formed not from biotite but by the impregnation with glauconite of the mudstone pellets that occur sparsely through the rocks. The grains so derived can be distinguished even when highly altered, because they contain inclusions of small fragments of quartz, distinctly smaller than most of the quartz grains in the groundmass (Plate IX., fig. 8).

Alteration of the Glauconite.

The alteration of the glauconite occurred either prior to or during lithification. In some sections (Bore No. 5, parish of Colquhoun) normal green and altered brown glauconite, with all intermediate stages, occur in the same section. The altered glauconite grains are sometimes rimmed by a thin margin of greenish glauconite, and the shrinkage cracks in the altered glauconite are filled with green or greenish-yellow glauconite mud.

A small, relatively pure sample of the altered glauconite containing some adherent quartz, was prepared by crushing the rock from No. 10 Government bore, parish of Colquhoun, with a rolling pin so as not to break the glauconite grains unduly, and then separating the glauconite from the bulk of the other minerals in the rock by suspension in bromoform of Specific Gravity 2·85. The glauconite-rich product obtained was then screened through a 60-mesh sieve. The material retained on the sieve consisted essentially of glauconite grains with a little adhering quartz. An analysis of this sample gave the composition shown in Table 1, Analysis No. 1. For glauconite to alter to a substance of this composition, the silica, potash and soda of the original mineral (compare Analyses Nos. 3 and 4) must have been replaced extensively by ferric oxide. Most observers (Collet and Lee, 1905; Cayeux, 1916; Milner, 1940), agree that glauconite is an unstable mineral which readily alters to limonite or ferruginous clay if exposed to oxidising conditions, so that this is a normal change for glauconite to undergo.

Such a change could have been brought about by weathering, by the action of iron-bearing solutions during lithification, or during deposition. The films of oxide on the occasional coarse, rounded grains of quartzite might be regarded as evidence of the passage of oxidizing iron-bearing water through the rock, but weathering or alteration during lithification seem to be ruled out because the green glauconitic mud that forms the cement of the rock, and fills the shrinkage cracks in the altered grains, is generally unaltered. The association of grains of green and brown glauconite in the same section, and the relatively unoxidized state of the pyrite grains in the rock, is further evidence supporting this conclusion. The fact that there is no concentration of alteration along the margins of shrinkage cracks shows that the alteration took place prior to shrinkage and while the material was still gelatinous.

TABLE 1.—COMPOSITION OF ALTERED AND NORMAL GLAUCONITE.

	1	2	3	4
SiO_2	25·81	27·74	53·61	49·47
Al_2O_3	7·27	13·02	9·56	5·59
Fe_2O_3	47·25	39·93	21·46	19·46
FeO	0·72	1·76	1·58	3·36
MgO	2·14	4·62	2·87	3·96
CaO	2·00	1·19	1·39	0·60
K_2O	2·31	0·95	3·49	8·04
Na_2O	nil	0·62	0·42	0·16
H_2O	11·89	10·85	5·96	8·54
CO_2	tr.	—	—	0·56
TiO_2	0·05	—	—	—
MnO	0·05	—	tr.	—
P_2O_5	0·35	—	—	1·06
Total	99·84	100·68	100·34	100·80

1. Altered glauconite (with some quartz) from the Miocene glauconite sandstone, Bore No. 10, parish of Colquhoun, Gippsland. *Analyst:* A. B. Edwards.
2. Decomposed glauconite, from recent marine deposits (quoted by Collet and Lee, Proc. Roy. Soc. Edin., 1905, vol. 26, pp. 238-278), from Murray and Renard, Deep Sea Deposits, Challenger Report, 1891).
3. Average of four analyses of recent glauconites collected by the Challenger expedition (Twenhofel, Treatise on Sedimentation, 1932, p. 456).
4. Purified glauconite from Cretaceous of New Jersey (Ibid.).

It seems probable, therefore, that this glauconite was altered to limonite or ferruginous clay during its deposition. Glauconite forming in the present oceans is sometimes subject to just such alteration, under conditions that are not yet defined (Collet and Lee, 1905). Comparison of Analysis No. 2 of Table 1 with Analysis No. 1 shows how closely such altered glauconite in deep sea deposits now forming can resemble the altered glauconite of this Miocene sandstone.

Collet and Lee have also shown that a brown ferruginous clay develops as a midstage in the formation of glauconite from pellets of grey clay, the green colour of the glauconite appearing only when potassium is introduced into the ferruginous clay. While this might apply to the brown glauconite developed from the mudstone pellets, it cannot be true for most of the altered glauconite, which was formed from biotite, because Galliher (1935) found no trace of such an intermediate stage in present-day glauconite forming directly from biotite.

Permeability and Porosity.

The permeability of the glauconitic sandstone was first measured by Croll (1939) who used material from the No. 1 Government bore, parish of Colquhoun, the No. 2 bore of the Lakes Entrance Development Co., and the No. 1 Kalimna bore. He obtained an average permeability of 223 millidarcies along the bedding, and of 15 millidarcies across the bedding. Individual measurements ranged from 5 millidarcies to 450 millidarcies. Thyer's unpublished measurements for the No. 10 bore indicate a lower permeability, with no consistent difference in directions parallel to and transverse to the bedding.

The appearance of the glauconitic sandstone in thin section throws little light on the variable permeability, and fails to account for the unusally high porosity of the dried rock. A piece of the air-dried core of No. 11 bore, parish of Colquhoun, was ground to a block measuring 7·5 x 6·0 x 6·0 cm. This was immersed in distilled water. Innumerable minute bubbles developed on the surface of the block, and showed only a very slight enlargement in size, until they escaped from the surface after one or more days, without other bubbles forming in their place. From three or four points, however, strong persistent streams of minute bubbles issued, several hundred bubbles being emitted per minute by each stream. These streams of bubbles continued for about two and a half hours. The bubbles from two such streams were trapped in inverted test tubes filled with water, from which it was found that the volumes of air emitted by the bubble streams amounted to 8 c.c. for one stream and nearly 10 c.c. for the other.

This feature of the emission of persistent streams of bubbles at one or two points was noted in practically all the specimens immersed in xylol-canada balsam solutions. In some instances, air from connected channelways issued at two points on the same specimen, and filling of the pores with solution led to the sudden cessation of one stream of bubbles, with a simultaneous increased emission in the other stream. This, coupled with the practical absence of bubble emission over large areas of the specimens, indicates that the larger open spaces in the rock tend to be localized, and so explains the great variability in permeability noted by Croll and Thyer. It was also noted, in the case of the large block of rock referred to above, that the bubble streams issued from faces at right angles to the bedding of the rock, rather than from faces parallel to the bedding, suggesting that, as Croll found, there may in some specimens be a somewhat greater permeability parallel to the bedding than across it.

The absorption ratio of this block of rock, after immersion for seven days, followed by drying for six hours at 105°C., and for a further three days in a sulphuric acid dessicator at room temperatures, was 17·8 per cent. Repetition gave a practically identical result. The specific gravity of the powdered rock from which the block was cut was 1·8, so that the apparent porosity of the block was approximately 32 per cent., which is of the same order as Thyer's more accurate measurements.

The absorption ratios measured in the same way on air-dried specimens from three other bore cores, namely No. 5 bore (1,238-43 feet), No. 8 bore (1,055 feet), and No. 10 bore (1,270-72 feet) were 10·5 per cent., 16·5 per cent., and 17·2 per cent. respectively, corresponding to apparent porosities of about 18 per cent., 29 per cent., and 31 per cent.

These high absorption ratios may be a measure of the pore space of the rock, or they may represent the capacity of the glauconitic mud cement to absorb water. If they measure the pore space of the rock, then since there are no obvious cavities or open spaces of this volume present, then such pore space can be accounted for only as due either to incomplete compaction allowing the existence of submicroscopic openings along the grain boundaries and in the glauconitic mud cement, or to air-drying of the rock inducing such openings in the cement.

To test this, specimens of the glauconitic sandstone were impregnated with a bright red xylol-balsam solution, so that the distribution of the balsam absorbed by the rock could be traced in thin section. The balsam was intensely coloured by means of an oil-soluble red dye, which is manufactured by British Drug

Houses, and is soluble in xylol. On evaporating out the xylol from the xylol-balsam solution on a hot plate, and heating the balsam until it set hard, the balsam retained the dye, though remaining perfectly transparent, and the colour remained fast. In thin sections the coloured balsam appeared pink.

A series of sections were prepared from air-dried material imgregnated with this red balsam from the cores of the No. 4, No. 6, No. 8, and No. 10 bores. The thin sections revealed only a few actual fractures, grain boundaries, or natural open spaces filled with pink balsam, and more often than not the shrinkage cracks in the grains of altered glauconite remained unfilled. The cement of glauconitic mud, however, was changed in colour from green or yellowish-green to a pinkish-brown, indicating that the dyed xylol-balsam solution had penetrated it more or less uniformly, presumably along submicroscopic openings. The pinkish colour was not due to reaction with the glauconitic mud cement, because over a period of about seven days the glauconitic mud cement slowly resumed its normal greenish colour, possibly as a result of slow oxidation of the dye-stuff, or of base exchange between it and the dye-stuff. It is concluded from this that the glauconitic mud forming the natural cement of the rock is highly porous in its air-dried state, the pore being chiefly capilliary openings, with diameters between 0·001 mm. and 0·0002 mm. The natural cement commonly constitutes 50 per cent. or more of the rock, so that if it were highly porous, such openings could account for much or all of the measured porosity.

It seems highly doubtful, however, that this measured porosity is the true porosity of the rock in its natural state, because even air-drying of the rock might cause a shrinkage of the natural cement and increase the porosity of the rock considerably.

Conclusion.

Glauconite can form from a variety of substances, provided that they become gelatinous through hydration (Takahashi, 1939, pp. 506-512). Such substances include faecal pellets, clay, colloidal and opaline silica, sponge spicules, fragments of volcanic glass, and minerals such as felspars, pyroxenes and micas. Which of these substances will be the dominant source in any one locality will depend partly on the mineral composition of the rocks from which the sedimentary materials are derived, and partly upon their relative susceptibility to hydration and gelatinization, other factors being equal.

Thus, in areas like that under consideration, where the sedimentary material was derived largely from granitic rocks, the substances most susceptible to glauconitization that will be present in abundance are biotite and felspar. The observations of Galliher (1935) and those described above show that in such circumstances biotite becomes hydrated and gelatinous much more readily than the associated felspars, so that the biotite tends to be altered to glauconite while the felspar remains fresh and unaltered.

The alteration of glauconite to ferruginous clay or limonite follows the same general course, whether the alteration takes place during deposition, during diagenesis, or subsequently as a result of weathering. Altered glauconite is not, therefore, of itself sufficient evidence of a disconformity in a sedimentary series.

It is also clear that the appearance of a rock in thin section is not always a reliable guide as to its porosity, and that special techniques, such as impregnating the rock with coloured media, are necessary to determine the nature of the open spaces. Moreover, in dealing with rocks which contain a considerable proportion of clays or clay-like substances, any drying of the rock may cause considerable shrinkage of such substances so that porosity measurements on such dried rock will not be a measure of the porosity of the rock in its natural state.

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Description of Plate.

Plate IX.

Fig. 1.—Oval grain of altered glauconite which has shrunk away from the enclosing matrix. The protuberances and indentations on the edge of the altered glauconite match similar fractures on the edge of the matrix, indicating that the void has not been caused by the grinding of the rock section. Below it is a sub-angular grain of altered glauconite. Ordinary light. × 100.

Fig. 2.—Oval and bean-shaped grains of altered glauconite showing pattern of shrinkage cracks filled by unaltered glauconite material similar to that forming the cement of the matrix of the rock. Ordinary light. × 100.

Fig. 3.—Oval grain of altered glauconite with internal shrinkage cracks. × 100.

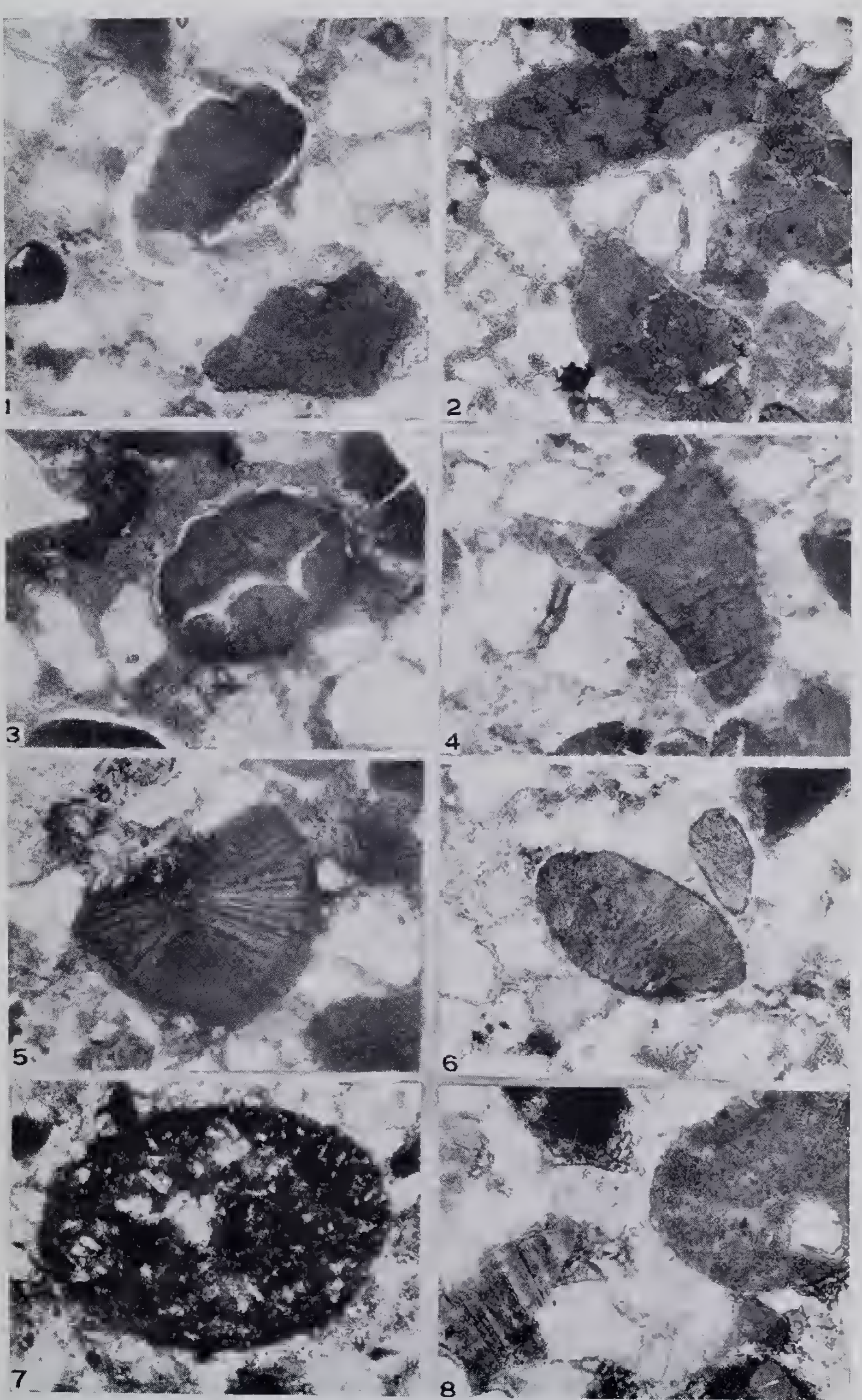
Fig. 4.—Curved grain of expanded biotite unequally swollen in the direction at right-angles to the cleavage planes. Ordinary light. × 100

Fig. 5.—Fan-shaped grain of expanded biotite. Ordinary light. × 100.

Fig. 6.—Grain of partly altered glauconite, showing traces of cleavage planes of original biotite. × 100.

Fig. 7.—Oval pellet of mudstone, containing minute inclusions of quartz. × 75.

Fig. 8.—Part of oval grain of altered glauconite on right, with enclosed grain of quartz smaller than quartz in matrix; and irregular flake of expanded biotite partly replaced along cleavages by green glauconite. × 100.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